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AUTOMATED WINDOWING PROCESSING FOR PUPIL DETECTION

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Abstract- **Video-based eye gaze detection systems are useful for eye-slaved support system for the severely disabled. The pupil center in the video image is a focal point to determine the eye gaze. Recently, to improve the disadvantages of traditional pupil detection methods, a pupil detection technique using two light sources (LEDs) and the image difference method was proposed [1]. In addition, for users or subjects wearing corrective eyeglasses a method for eliminating the images of the light sources reflected in the glass lens was proposed. However, image-processing hardware for implementing these methods is rather expensive. In the present paper, the hardware construction is replaced by a construction consisting of a combination of a conventional image grabber and a personal computer. An algorithm for windowing around the pupil image with an automatic thresholding method for pupil detection is proposed. The results show that the algorithm works well when the user or the subject is wearing eyeglasses and under normal ambient lighting conditions. The calculation time is quick enough for real time processing. These algorithms would contribute to consistent and reliable pupil detection.**

Keywords– pupil detection, image processing, eye-gaze detection, support system, the disabled

I. INTRODUCTION

Development of outstanding eye gaze (or line of sight) detection methods is desired for several fields, such as for man-machine interfaces and for psychophysical or behavioral studies. It is very useful especially for many of the physically disadvantaged, such as amyotrophic lateral sclerosis patients, who cannot use basic body movements accurately but do indeed have eye movement ability. Such a user is able to control peripheral assistant devices or can communicate with others through a pointer with the computer presenting hierarchal structural menu options on a computer screen [2].

Generally the line of sight is determined by the relative position between the pupil center and glint (the corneal reflection light of the light source) in the image because the glint does not move as much as the pupil image [2]-[4]. There are two conventional pupil detection methods: bright eye [2][4] and dark eye methods [5][6]. Recently, to eliminate the shortcomings of these conventional methods, a combination of the two methods was proposed: a pupil detection method using two light sources and the image difference method [1]. In this method, one light source set coaxial with the camera is switched on during the odd fields of the NTSC video signal and another one set uncoaxial with the camera is switched on during the even fields. The difference images are obtained by subtracting the even field images from the consecutive odd field images. Since the background almost vanishes in the difference image, a threshold setting for pupil detection is much easier. We have also proposed a method that allows the users to wear corrective eyeglasses. It used a special hardware device for image processing. However, we did not describe the thresholding methods for eliminating the glass reflection light (GRL) and detecting the pupil image.

In general, the GRL tends to make pupil detection unstable. For consistent and reliable pupil detection, the most important thing is to consistently window around the pupil image and to mask the noise in the background (including the GRL).

The present paper proposes an algorithm for windowing around the pupil image on the base of the difference pupil detection method, which works on a relatively cheap construction (a personal computer and an image grabber). It is shown that, in the remote condition (the distance between the camera and eye is 50 - 65 cm) and in normal ambient lighting conditions, the algorithm works well on the images including the GRL.

II. METHODS

A. Experimental setups

Optical devices for experiment have been described elsewhere [1]. The images of an eye were captured by the image grabber (brightness depth: 0 - 255 with a resolution of 640Hx240V pixels for each field, 640Hx480V pixels for one frame.

B. Algorithm of Microprocessor-Based Windowing Process in Each Frame

Step 1. **Making reduced images and histogram for odd and even field images.** To shorten the time for accessing the image grabber, we sampled each field

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Abstract

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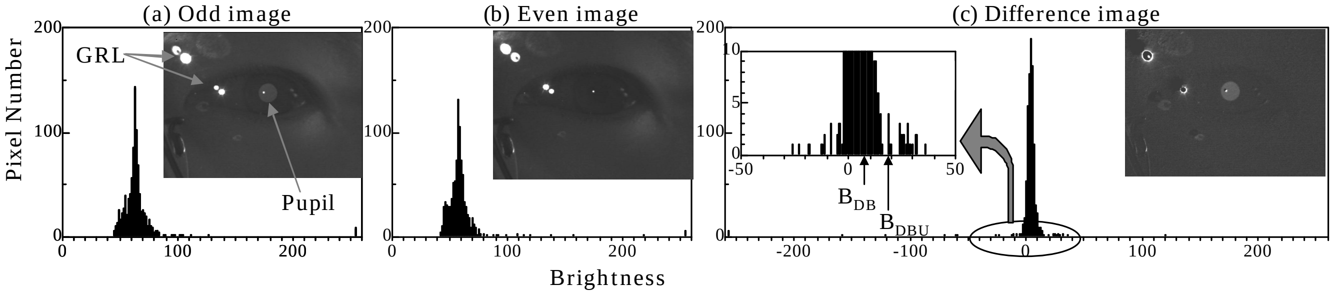

Fig. 1. Sample images and their brightness histograms.

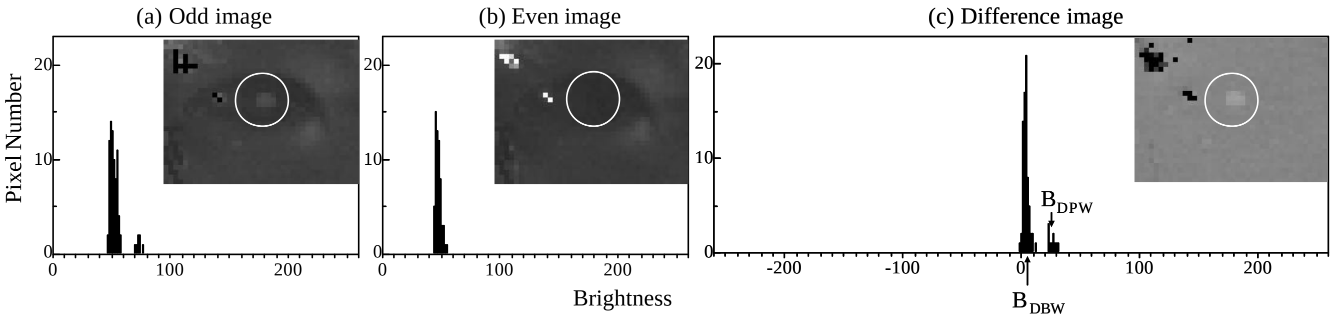

Fig. 2. The temporal window (TW) and the brightness histograms in TW.

image at every 16 pixels horizontally and every 8 pixels vertically. The total sampled pixel numbers were 1200 (40Hx30V) for each odd and even field, respectively (Fig. 2(a) and (b)).

Step 2. **Removing saturated pixels in brightness and their neighboring pixels from odd image.** A fraction of the GRL image always saturates (level 255) in the image. However, there is the possibility that the surroundings of the saturated GRL image are higher in brightness than the pupil image. The areas may be mistakenly judged as the pupil area. In addition, the glint usually saturates, this may be mistakenly judged as the GRL.

All pixels in the odd image are scanned horizontally. Since the glint does not consist of more than one pixel, the saturated pixels and one neighboring pixel on the left and the right sides of the saturated pixels are converted to zero brightness level when sequential saturated pixels are detected. Next, all pixels are vertically scanned and processed in the same way. Finally, the remaining saturated pixels are converted to zero level (Fig. 2(c)).

Step 3. **Differentiation of even image from odd image.** The difference image, as shown in Fig. 2(d), was made by subtracting the even image (Fig. 2(b)) from the odd image (Fig. 2(c)). At the same time, the brightness histogram of the difference image (Fig. 1 (c)) is made.

Step 4. **Determination of a temporary threshold for pupil detection in the difference image.** The histogram for the difference image was scanned while adding the pixel number in each bin from -255 toward 255. The brightness level when the sum of the numbers first exceeds half of the total (600 pixels) is determined as the background brightness (B_{DB} in Fig. 1(c)). Next, while further incrementing the brightness level from B_{DB}, the level when the pixel number first becomes zero is defined as the upper limit of the background brightness (B_{DBU} in Fig. 1(c)).

Step 5. **Solitary island elimination in the difference image.** There is a possibility that the wrecks of the GRL image brighter than the B_{DBU} remain as solitary islands as shown in Fig. 2(d). If this step is not applied, the pupil image binarized by the B_{DBU} becomes as shown in Fig. 2(g).

The pupil image consists of a relatively large cluster of pixels. In contrast, each wreck of the GRL image generally consists of a few pixels. So, all pixels in the difference image are horizontally scanned. When the brightness levels of more than one of the four surrounding pixels (the upper, lower, right, and left pixels) are brighter than B_{DBU} or as bright as -256, the focused pixel is judged to be a part of a solitary island and its brightness level is replaced by -256. Fig. 2(f) shows the image after binarizing the obtained image using B_{DBU}.

Step 6. **Determination of the pixel number center of gravity (PNC) of the pupil in the difference image.**

By horizontally scanning the difference image (Fig. 2 (e)) from the top to the bottom while counting the pixels brighter than B_{DBU} (high pixel, HP), the total of the HP is determined as the total high pixel number (THPN). Next, the image is horizontally scanned again in the same way while counting the HP. A y coordinate when the total of the HP first exceeds half of the THPN is determined as that of the PNC of the pupil image. Finally, while vertically counting the HP from the left to right, a x coordinate of the PNC is determined in the same way.

***Step 7.* Determination of some thresholds using images in first temporary window (TW).** To perfectly eliminate the GRL and other noise in the background, a circular TW whose center is the PNC, having a radius of 5 mm of actual size, is applied (circles in Fig. 3). The brightness histograms for the difference images are made within the TW (Fig. 3(c)). At the same time, within the TW in the difference image, the pixels brighter than B_{DBU} and those not brighter than B_{DBU} are counted as the pupil and background pixel numbers (N_P and N_B), respectively.

The pixel numbers of the histogram for the difference image are added from -255 toward 255 in the brightness level. The brightness level when the sum exceeds half of the N_B is determined as the background brightness for the difference image within the TW (B_{DBW}). Next, the pixel numbers of the same histogram are added from 255 toward -255 in the brightness level. The brightness level when the sum exceeds half of the N_P is determined as the pupil brightness (B_{DPW}). A threshold for pupil detection (Th_P) is determined using the following equation:

$$Th_P = (B_{DBW} + B_{DPW})/2 \qquad (1)$$

***Step 8.* Remaking of the difference image in the TW.** The reduced difference image within the TW is remade using the odd image (Fig. 2(c)) and the even image (Fig. 2 (b)).

***Step 9.* Determination of the pupil pixel number (PPN) and the PNC of the pupil pixels in the TW.** By scanning only the pixels in the TW, the PNC of the pixels having the brightness levels higher than Th_P is determined as the PNC of the pupil pixels by the same procedure as in Step 6. In this step, the number of the pupil pixels (PPN) is also counted.

***Step 10.* Setting an appropriate sized window around the pupil image.** The TW having a radius of 5 mm is usually too big compared to the actual pupil image size. Accordingly, a window as small as possible should be applied around the pupil image. First, a TW having a diameter of 1 mm of actual size is applied to the PNC of the pupil pixels obtained in Step 9. The TW size is increased gradually while adjusting the TW center to the updated PNC. In the final TW, the maximum of the distances between each of the pupil pixels and the final PNC is obtained. The maximum distance +1 and the final PNC are determined as the radius and the center of the final window, respectively.

***Step 11.* Converting the final window to the original image scale.** The center coordinates and radius of the final window are converted from the reduced scale to the ordinal image scale.

III. RESULTS

Fig. 4 shows the results of windowing the pupil images with the GRL, eyeglasses frame, and the other backgrounds. These images are the typical ones obtained in the following experiment. The circle and the intersection of the bars indicate the window applied and its center coordinates, respectively. The appropriate sized windows were applied to each appropriate position.

In the real time experiment, a computer display was placed approximately 65 cm facing a subject. The screen of the display was brightened by another personal computer to mimic an actual use situation. On the screen nine small markers were arranged equally (3 by 3). The subject was asked to look at each of the

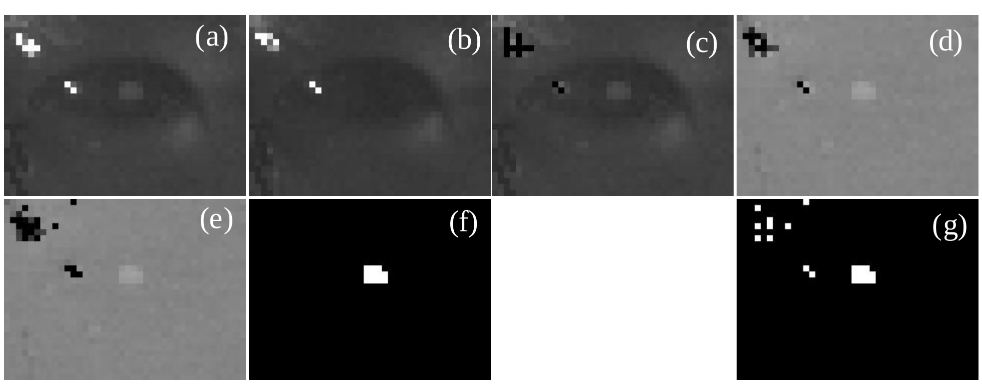

Fig. 3. Sample images in each step of the windowing process.

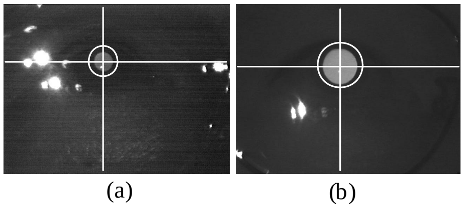

Fig. 4. Results of windowing process in static experiment.

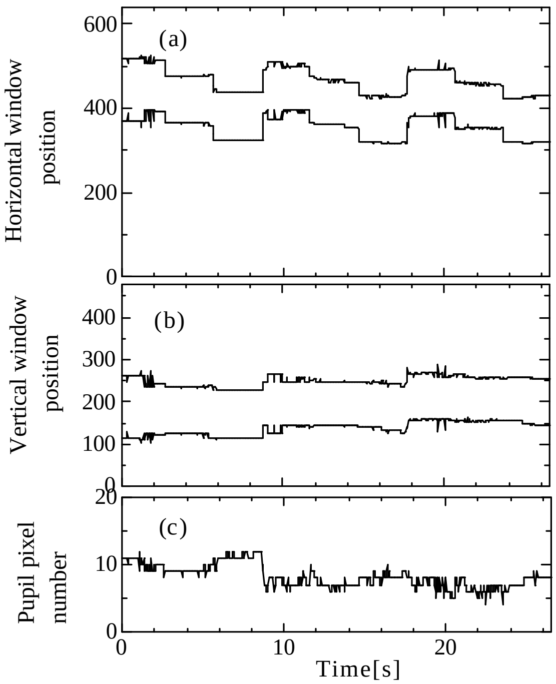

Fig. 5. Results of windowing process in real time experiment.

nine markers successively (every 3 seconds). In Fig. 5, the top and middle panel indicate the coordinate of the extremes of the window. The bottom panel indicates the PPN. The nonzero PPN and the feasible movements of the center and extremes of the window indicate that the window was consistently and reliably applied to the pupil image appropriately.

IV. Discussion

When the eye is directed to a point far from the camera axis, the sclera easily brightens. This disturbs a wide range of detectors of the line of sight. However, we confirmed that this windowing process eliminates this problem.

We have already begun a study of precise pupil center detection within the window. We know empirically that the threshold determined for the windowing process (Th_P) is also very suitable for the threshold for binarizing the pupil image for the detailed analysis inside the window.

In the recursive temporary windowing processing, the TW was gradually increased from a small area in each frame of image. This processing is extremely effective for appropriate windowing in the case that a source of noise, relatively large but not larger than the pupil image, exists beside the pupil. Such a case may occur in the case where the GRL does not saturate in the odd image. This size-increasing method is also effective for shortening the calculation time compared to a size-decreasing method [8] because it takes less time for calculation in smaller sized TWs.

V. Conclusions

We improved the pupil detection method using two light sources and the image difference method we previously proposed as follows: (1) For convenience and low cost, a conventional image grabber and a personal computer were used for image analysis instead of the special hardware construction in the previous study [1]. (2) A circular window of minimum dimensions could be applied around the pupil image reliably in real time. (3) Fully automated thresholding for pupil detection was realized. (4) All the processes listed above worked well on subjects wearing eyeglasses. (5) The processing time for an image including a typical sized pupil and the glass reflections was only 7.2 ms on the Pentium II 266 MHz-based computer.

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